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Agency in the making: analyzing students' transformative agency in a school-based makerspace

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ABSTRACT

Despite the potential of digitally enhanced learning environments for supporting twenty-first-century learning and educational change, there is a dearth of research knowledge on students' transformative agency in their use of digital technologies and media within these contexts. Transformative agency accounts for young people's initiative and commitment to transform their activity and its context(s) for personal and/or academic ends. This paper reports an investigation of students' transformative agency in a novel, student-centered design and learning environment, referred to as a makerspace. We present our empirical findings as a narrative, illustrating how transformative agency emerged and developed via three intertwined discursive and action-level manifestations of such agency, namely "deviating", "switching", and "transfiguring", in the social activity of a group of four 5th grade students participating in the makerspace environment over one school semester. Our study makes an original contribution to the research on students' transformative agency and its temporal unfolding in a novel digitally enhanced learning environment.

Introduction

The emergence and development of student and teacher agency have become a central topic in the academic and practitioner literature concerning students' educational opportunity and educational change in general. Ongoing expansion of digital technologies and media aiming at major changes in teaching and learning practices at schools calls for enhanced agency of young people and their teachers (Ito et al., 2013; Kumpulainen, Kajamaa, & Rajala, 2018).

Digitally enhanced learning environments often referred to as "makerspaces", have aroused recent educational interest as a means of supporting students' learning (see, e.g., Blikstein, 2013; Kafai, Fields, & Searle, 2014; Kajamaa, Kumpulainen, & Rajala, 2018; Kumpulainen et al., 2018; Lindtner, 2014; Martinez & Stager, 2013; Peppler, Halverson, & Kafai, 2016). Makerspaces typically account for spaces that support student-centered pedagogies and student engagement in hands-on creative activities with technologies, fostering students' science, technology, engineering and mathematics (STEM) learning, and twenty-first century skills (see, e.g., Benton, Mullins, Shelley, & Dempsey, 2013; Bevan et al., 2016; Calabrese Barton & Tan, 2018; Honey & Kanter, 2013). Yet, limited research attention has been paid to students' transformative agency in their use of digital technologies and media within the makerspaces.

Socio-cultural and cultural-historical studies define transformative agency as a cognitive transformation and reframing process evidenced in young people's initiative and commitment to transform the context(s) of their activity for personal, academic, working life, and/or civic ends (see, e.g., Ito et al., 2013; Rajala, Hilppö, Lipponen, & Kumpulainen, 2013; Stetsenko, 2008). Transformative agency "develops and is maintained in collective interaction over time when agentive actions gain

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their meaning, their consequences and their continuity in the interplay between individuals and their collective" (Engeström, 2007). Transformative agency can manifest itself in social activity and discourse that breaks away from a given frame of action and/or takes initiatives to transform it (Virkkunen, 2006, p. 49). Moreover, it is always related to a socio-material context and practical actions (Haapasaari, Engeström, & Kerosuo, 2014).

The site of our research to investigate students' transformative agency is a city-run Finnish comprehensive school which has recently undergone a major curriculum reform and whose formal classroom learning environments were extended by introducing a new digital makerspace called "the FUSE studio". The aim of this studio is to enhance a student's interest-driven, collective and inclusive learning. It also potentially enhances the student's digital literacy and STEM learning (Stevens et al., 2016).

In this article, our analysis focuses on the emergence and development of transformative agency of a group of four students taking part in activities at the FUSE studio. We analyzed the emergence and development of transformative agency over one school semester to capture its temporal unfolding. Our research was guided by the following question: How can students' transformative agency manifest over time in the digitally enhanced makerspace of the FUSE studio?

Socio-cultural and cultural-historical studies on agency

Opportunities for active participation and intentional membership in educational activities have been found to be important in positioning students as actors and authors of their learning (Brown & Renshaw, 2006; Greeno, 2006; Kumpulainen & Lipponen, 2010). Previous socio-cultural research has explored student and teacher agency in connection with the transformation of local educational practices and school systems, and emphasized student agency as an important mediator in achieving personal and social change in local educational contexts (Gutiérrez & Calabrese Barton, 2015; Kumpulainen et al., 2018; Mäkitalo, 2016; Siry, Wilmes, & Haus, 2016).

From the socio-cultural perspective, agency is not a primary characteristic of an individual, but is a dynamic, complex, relational and cultural process, mediated by conceptual and practical signs and tools (Holland, Lachicotte, Skinner, & Cain, 1998; Wertsch & Rupert, 1993). It has been pointed out that students' agency is a key to their relational engagement (Edwards, 2011). Even in most restricted settings characterized by accountability and control mechanisms, there is room for students to achieve some degree of agency (Buxton et al., 2015; Gresalfi, Martin, Hand, & Greeno, 2009; Rainio, 2008a; Robinson, 2012). Further, agency holds transformative potential and it can be seen as the capacity of people to act upon, influence and transform their activities, circumstances (Gutiérrez & Calabrese Barton, 2015; Holland et al., 1998; Lasky, 2005; Lipponen & Kumpulainen, 2011).

Taking a socio-cultural lens, Rainio (2008a) has investigated different formulations and development of agency in elementary school children's "playworld" activity. Stressing that agency should not be considered to be a stable property, belief or an attitude of an individual, she highlights that agency "must be understood as a complex and contradictory process developed over time but simultaneously grounded in local interactions, to the roles and positions available to students and teachers" (p. 116). In another study, Rainio (2008b) also illuminates how students' agency may develop dynamically and expand, when teachers help them to enact it creatively over time in a school context. These studies echo more recent activity-theoretical studies viewing agency as interactive and collaborative, and as emerging in creative, often tension-laden encounters among collectives (Miettinen, 2013), and with studies which argue that transformative agency involves initiation and volitional actions from the individuals and holds the potential for expansive learning, including the generation of new motives, concepts and practices (Engeström, 2006).

In this study, we take a socio-cultural and cultural-historical perspective, viewing transformative agency as a continuous, non-linear and tension-laden process, always related to the socio-material context and practical actions. We hold that transformative agency manifests itself in discourse and

social activity that breaks away from a given frame of action and/or takes initiatives to transform it (Virkkunen, 2006, p. 49). Further, we define transformative agency as a reframing process evidenced in young people's initiative and commitment to transform their activity and its context(s) for personal and/or academic ends (Ito et al., 2013; Rajala et al., 2013; Stetsenko, 2008). Transformative agency can also be viewed as an orientation or "a transformative activist stance", in which the actor, instead of adapting to their environment, makes efforts to transform existing activity and practices for personal or collective ends. In this process, the active engagements of the individual contribute not only to the transformation of the joint activity, but also potentially to the development of their own identity and learning (Vianna & Stetsenko, 2011). Typically, the development and sustainability of such transformative agency takes place in interactions between individuals and collectives over time (Engeström, 2007).

Researching and understanding transformative agency

The theoretical notion of transformative agency has been developed and applied in empirical analysis of the learning of adults in work settings by researchers applying cultural-historical activity theory (CHAT) (Engeström, 2006; Haapasaari et al., 2014; Sannino, 2008; Sannino, Engeström, & Lemos, 2016; Virkkunen, 2006). The interventionist line of research applying CHAT considers the emergence of transformative agency to be an important outcome in formative interventions (Engeström, 2011; Virkkunen & Newhamn, 2013).

From this perspective "actions and expressions of transformative agency emerge when people are placed in demanding situations and are given an opportunity to analyze, envision and redesign their activity collaboratively, with the help of mediating conceptual instruments" (Haapasaari et al., 2014, p. 259). These studies emphasize resistance, conflicts and tensions as important mediators, mediating the interaction and innovative learning and knowledge advancement. From this perspective, the evolution of agentive actions is a lengthy "expansive" learning process in which learners strive to become agents of their own learning, and reshaping their collective activity (Haapasaari et al., 2014). This refers to transformative action and "learning something that is not yet there", is expansive and can thus never be fully controlled by instructors or interventionists (Engeström, 2001, 2011; Sannino et al., 2016). On this basis, transformative agency is seen as collective and a source of surprise and novelty, and as a driver for change. Transformative agency can also be seen as a neighboring concept of the relational agency focused on the learning and development that occurs as people work together aiming at answering to complex problems (Edwards, 2011, 2017). Yet, it is not limited to the relations of an individual expert or situations but evolves in interaction over time and seeks out opportunities for collective developmental efforts to generate systemic changes (Haapasaari et al., 2014).

In the existing literature, the emergence and development of transformative agency have been analyzed in the context of formative interventions carried out in different work contexts, such as in a school (Sannino, 2008), in a service company (Haapasaari et al., 2014) or in a horticultural firm (Vänninen, Pereira-Querol, & Engeström, 2015). The aim of these studies and their methodology is to activate employees' agency, that is, creating conditions in which employees can be active, responsible and critical (re-)designers of their collective work activity and future. Moreover, in formative interventions, researchers initiate learning actions promoting participants' transformative agency and the development of work practices. These studies show that transformative agency is a demanding and often lengthy process of learning, design, and implementation, distributed in time (see Haapasaari et al., 2014; Vänninen et al., 2015).

Deviating from the existing cultural-historical studies on transformative agency, in our study, we did not collect the data by carrying out a formative intervention. Instead, our study is the first attempt to investigate the emergence of students' (9–12 years old) transformative agency over time in a novel makerspace called "the FUSE studio". The FUSE studio is based upon a student's interest-driven pedagogical approach, in which students are free to select which "challenges" to pursue and

when to move on. Providing new materialities and opportunities for the development of student-centered learning, and at the same time being located in the tension-laden intersection between formal schooling and the students' out-of-school life, we find the FUSE studio to be an especially intriguing research context for the study of students' transformative agency.

Research context

The context of our study is a Finnish city-run comprehensive school with 535 students and 28 teachers at the primary level. The local curriculum of the school follows the new Finnish National Core Curriculum for Basic Education (NCC, 2014) and strives for student-centeredness and stresses design and digital learning, which are considered to enhance students' creative problem-solving skills across the curriculum. In 2016, as a response to the new curriculum requirements, the school introduced the FUSE studio (www.fusestudio.net) as part of its elective courses. This infrastructure was originally created by a team of researchers from Northwestern University in the USA.

The FUSE studio is a digitally enhanced learning environment that is focused on design and making activities, i.e. Science, Technology, Engineering, Arts and Mathematics (STEAM) tasks or challenges aimed at enhancing a student's interest-driven, collective and inclusive learning. Each FUSE challenge is designed to engage students in different STEAM topics and skill sets. The challenges are included in the computer-based infrastructure of the FUSE (next referred to as the FUSE website), where the students carry them out individually and in groups. The challenges are accompanied by various tools, such as computers, 3D printers and other materials (e.g., a foam rubber, a marble, tape and scissors, which we refer to as "artifacts"), as well as instructions on how to process the challenges. The assessment of the student's participation and learning does not include grading, but is carried out by utilizing photographs, video or other digital artifacts and the student's own documentation (Stevens & Jona, 2017; Stevens et al., 2016).

The American students who have personally experienced the FUSE studio, have recorded the many challenges and present these on the FUSE website (www.fusestudio.net) for other students carrying them. In our view, the website draws a picture of the students participating in the FUSE studio as competent, "real designers" and as agentive solvers of challenges. What makes the FUSE studio especially interest- and learner-driven is that the challenges are tightly connected to the everyday, out-of-school lives of the students, and that they follow the basic logic of video game design principles (Salen & Zimmerman, 2005), which are familiar and of interest to the student-users, at least in the context of Finland.

Data sources

Our primary data comprise 111 h of transcribed video recordings and field notes of students (N = 94) aged between 9 and 12 years old and their teachers carrying out design and making activities. The video recordings were collected intermittently over a period of one academic year. Due to the elective nature of the FUSE course, the groups consisted of students from several classes. Group 1 consisted of 32 students (22 boys and 10 girls), Group 2 consisted of 30 students (19 boys and 11 girls) and Group 3 consisted of 32 students (19 boys and 13 girls). Each group was supported by two to four teachers and teaching assistants.

In this paper, we focus on analyzing the transformative agency "in the making" of a group of 5th-grade students (all girls) called Oona, Peppi, Riina and Silja (pseudonyms) in the FUSE studio over one school semester, from September to December 2016. The girls attended the FUSE studio weekly and decided among themselves the composition of their group and the challenges from the FUSE website they worked with, for each of the FUSE studio sessions. We chose to follow this group in four FUSE sessions in which their composition and the facilitating teachers remained the same and they carried out a rich variety of challenges. Two teachers (John and Rose) were present at all the FUSE sessions this group attended. The FUSE sessions on which we focused were situated in three of

the FUSE challenges, namely the Solar Roller (45 min), Electric Apparel (60 min) and Jewelry Designer (two sessions, approx. 60 min) challenges. All of these challenges were new to the students participating in the FUSE studio for the first time.

The video data and field notes of students' and teachers' social activity in the FUSE studio were transcribed verbatim. The emergence and the development of their transformative agency have been illuminated by analyzing direct quotes from the data, presented in the Findings section, within the narrative. Examples 1 and 2 present the analysis of singular FUSE challenges, the Solar Roller and the Electric Apparel. In Example 2, presented in the Findings section, we focused on Oona and Peppi, working as a pair on the Electric Apparel challenge for practical reasons, as our video camera was directed at them during this challenge and not at the second pair of girls Riina and Silja. In Example 3, the third and the fourth FUSE sessions have been analyzed as a group of four during both sessions.

Methods of data analysis

Our analytic approach can be defined as abductive, involving repeated iterations between theory and data (Van Maanen, Sørensen, & Terence, 2007). Our analytical procedure was first data driven. The data were approached inductively by approaching the video corpus as a whole and then focusing on selected events in greater depth (Derry et al., 2010). In line with previous socio-cultural and cultural-historical studies on agency (see also Haapasaari et al., 2014; Rainio, 2008a), we also paid attention to the tensions emerging in the interactions of the students and their teachers during the design and making activities.

Our analysis involved an orientation similar to Engeström's notion of expansive learning (2001), viewing transformative agency as emerging and developing in a cyclic process of interaction and non-linear actions of learning. We first divided the transcribed data into topical interaction episodes with a beginning and an end. From the episodes, we analyzed discursive expressions of transformative agency in the speaking turns in the interaction. In addition, we investigated transformative agency from actions, emerging through the participants' use of mediating means (i.e., language, digital artifacts and other materials and tools). From these, we identified the discussion topics and actions through which agency is enacted within design and making activities that contributed to the emergence of transformative agency.

Our empirical findings have been presented as a narrative, illustrating the emergence and development of transformative agency in the social activity of a group of students during one school semester. Narrative is an especially useful and powerful way for human agency to be illuminated over time as it allows for the interpretation and analysis of meaning, social action, human experience, a multiplicity of meanings and knowledge, and the complexity of social elements and the moral elements of human life (Bruner, 1986). The narrative, based on our empirical data, evidences three, discursive and action-level indications of transformative agency, namely deviating, switching and transfiguring, in the socially and materially mediated design and making activity of the students during their engagement in the FUSE Studio makerspace.

More precisely, we traced the indications of transformative agency in an iterative process involving: 1) acts of deviating which emerged through interaction and the use of digital and other mediating means/tools in our data. Here the students expressed criticism, frustration and/or dissatisfaction toward the instructions given by their teacher(s) or by the FUSE website discursively, or by other actions, simultaneously demonstrating a will to depart from those and to act in another way, more meaningful to them; 2) switching refers to the students' creative initiatives and actions aimed at overcoming the tensions and the feelings of frustration and dissatisfaction. This was done, for example, by the group members experimenting with new roles, with an overall aim to progress with the challenge independently from the teacher and the instructions, transforming the learning task to fit the student's needs in a certain, meaningful way; and 3) transfiguring which stands for expressions and actions which changed the direction, form and meaning of the learning activity in the makerspace, usually partially, and at times quite radically toward a shared object. This happened

by legitimizing and sustaining the new solutions and the transformed roles of the participants, for example, by taking an expert position and explaining the challenge at hand to a peer student or the teacher from a novel perspective. To note, these three main discursive and action-level indications of transformative agency appeared in our data as intertwined and in a cyclic, non-linear manner, across the analyzed four FUSE sessions.

Findings: students' transformative agency "in the making"

Our study reveals three intertwined discursive and action-level manifestations of students' transformative agency, namely "deviating", "switching" and "transfiguring", in the design and making activity of a group of four students. Next, we illuminate how the FUSE studio as a novel, digitally enhanced makerspace, provided a favorable context for the emergence and development of these forms of transformative agency. Example 1 illustrates how tensions triggered the students deviating from the instructions given by the teacher and the FUSE website. Example 2, shows how the participants begin to switch their roles to overcome the tensions, giving rise to opportunities for the students' progress, independent from the teacher, via developing creative and novel solutions to the challenge at hand. In Example 3, we can see further changes in the direction, form and meaning of the activity for the students.

First example: deviating from the given instructions

At the beginning of the semester, in September 2016, the four girls Oona, Peppi, Riina and Silja gathered and chose to work on the FUSE challenge called "the Solar Roller", which aimed to develop students' understanding of the functioning of a car. The aim of the challenge is to move the car by charging it with power from the lamp provided in the challenge kit. The kit also includes a frame for the car, a motor, a lamp, wires for coupling, a tape measure, two flags, and three solar panels of different sizes to choose from. The students can self-access written instructions and video tutorials on the FUSE website to carry out the challenge. Two teachers, John and Rose, are in the room to assist the students.

As the group of four starts working, Oona is sitting in front of a computer and is watching the video tutorial and reading the instructions. The other group members are gathered around the challenge kit to collect the necessary equipment for the challenge. Riina occasionally goes up to Oona to have a look at the instructions, trying to figure out what the different pieces of equipment in the challenge kit are to be used for. Then, they move into jointly building the car with the instructions and the equipment provided. Everything seems to proceed well, but then a problem occurs as the car would not start moving. After some unsuccessful trials, Oona turns to the teacher John for with a question.

Oona (to John): It happened to us, that we have looked at the instructions, we only need to put a motor and that and there are still all these other parts – And when we test it, it does not move!

John: It is possible that the panel does not work, but let's just test first. So, when you use the lamp, you'd get the car moving (solar power). Did you try it with the lamp?

Oona: Yes, we did! And so that the lamp was really close to the panel (competently)

John: Alright, now we will cheat a little bit and use the battery to test if the motor works. Here is the battery, just make sure it goes the right way round. It can only be put there in one way. Plus goes to plus and minus goes to minus (…).

In this example, we can witness how Oona, using the collective 'us' and 'we', when approaching the teacher John, conceptualizes the challenge as being relatively easy to carry out jointly by the group (to us … we have … we only need to …). By replying to John (Yes, we did!), she emphasizes the proactive nature and the competence of the group. When the teacher then unexpectedly

encourages the group to cheat against the original instructions to get the car moving, especially Oona seems unsatisfied, but the girls do this. To the girls' disappointment, the car then starts moving backwards, creating a tension between Oona and the teacher.

Then, Oona, who prior to the task, had taken the responsibility of reading the instructions of the challenge on the computer for the group, takes a leadership role, to enable them to move the process forward. For this, she starts to explain the instructions in detail to the other group members and invites the others to envision possible solutions to the problem. By so doing, she demonstrates a will to depart from the given instructions and to act in a way that is more meaningful to her and to her peers.

Riina and Silja seem very attentive, but Peppi, however, does not favor Oona's idea of continuing independently with the challenge, stressing that they should ask for the teacher's verification of how to proceed with the challenge. As Oona is reluctant about relying on the teacher, Peppi then leaves the group for a moment and goes to ask the teacher for help, creating a tension between her and Oona. The teacher comes up to the group and explains the instructions further. Oona opposes the teacher's involvement by withdrawing from this discussion.

Thereafter, Oona, Silja and Riina momentarily leave to get a new set of panels to see whether this is causing the problem. Again, Oona takes the lead when they install a new panel and test the car. She then admits that they cannot move forward in the task without the teacher's help. However, instead of asking for the help herself, she directs Riina to do so. Riina, in the front of the group, expresses strong disappointment toward Oona, who had strongly encouraged their autonomy as a group, giving up this autonomy and wanting to rely on the teacher. Oona, from her part, does not seem to trust Riina in giving the instructions. As illustrated in the next excerpt, this causes a quarrel between Oona and Riina.

Oona: Alright, will you (Riina) go and ask the teacher?
Riina: No, Oona, you try to turn it! [seemingly forbidding Oona to turn to John and giving her direction on how to direct the light towards the solar panel differently].
Oona: No! It should move like this, then it can't move like this (Oona's tone is determined, and she is apparently not willing to listen to Riina)
Riina: That's right but – whatever – not symmetrical but … I don't know (frustrated).

Oona then asks the teacher John and he verifies to the group how the light should be turned toward the solar panel. To the girls' surprise, the explanation turns out to be exactly the same, which Riina had just given to Oona and the other group members, but which at that moment, they did not try proceeding with. As a result, the four girls seem low-spirited as their expectations toward the challenge as a group (being stuck), the teacher (asking to cheat) and themselves (giving up too easily) were not met. The students, however, then without relying on instructions, try to start the car again. After several trial and error attempts, Silja (who had been mainly quiet) moves the car parts in a way which leads to the functioning of the car and to the successful completion the first level of the Solar Roller challenge. Then the session finishes and the students leave the room.

To sum up, the FUSE session illustrates how the emergence of transformative agency is a process triggered by multiple tensions in the socially and materially mediated interaction. In the context of the digitally enhanced makerspace, there were multiple tensions related to the instructions provided by the FUSE website and the teacher, and the power relations between teachers and the students, as well as among the group of students. We consider these tensions to be crucial as they seemed to trigger the group's discursive expressions and actions to deviate from the teacher-given instructions, and to accomplish the challenge creatively and independently. Silja's independent, creative (non-discursive) act of trying out a new solution can be seen as an important agentive act and a deviation, not only from the teachers' instructions, but also from the suggestions made by her peers.

However, in this example, the group heavily relied on the expertise of the teacher throughout the session. The well-framed instructions given by the teacher mediated the interaction, and in our

interpretation, limited the degree of the students' transformative agency manifested in the design and making activities. By the end, the group had accomplished only the first level of the three-level Solar Roller challenge and lost its interest and motivation to return to the same challenge, to complete its remaining levels in the next FUSE session.

Second example: switching the roles and the direction of the activity towards being student-driven

When October 2016 arrives, Oona, Peppi, Riina, and Silja gather at the FUSE studio and decide to work in pairs. Without verbalizing this decision, Oona and Peppi and Riina and Silja pair up and sit next to one another in pairs. Oona and Peppi start working on "the Electric Apparel" challenge, Riina and Silja on "the Led Color Lights" challenge. They seem to randomly choose to work on these two new FUSE challenges. Two teachers, John and Rose, are in the room to assist the students.

In the Electric Apparel challenge, carried out by Oona and Peppi, the students are instructed by the FUSE website to design and manufacture a garment with LED lights attached to it (LED is an acronym for "light emitting diode"). In doing so, the students will first practice lighting the lights on the fabric. After that, they attach the lights to a piece of their clothing (e.g., gloves, etc.). Oona and Peppi read the instructions together from the FUSE website, and start looking at and tinkering with the materials in the Electric Apparel challenge kit.

Oona puts a battery and a LED light on her hand, she connects the LED light to the battery. Soon, she and Peppi start to feel confused about the instructions and are uncertain on how to proceed with the challenge. However, they persistently undertake multiple trials in trying to light up the led-lights, but do not succeed. Instead of relying on their teacher, in this challenge, they turn for advice to their peer Miina, who has carried out this challenge previously. Oona and Peppi, who had disagreements in the first challenge, and Miina then focus jointly and enthusiastically (e.g., Peppi: Oooh! Cool!) on this new challenge. The nature of the interaction switches during this challenge, from tension-laden and mainly negative as in the first example, to one that is creative and mostly positive. As demonstrated in the next excerpt, the girls were enthusiastic about the challenge and seemed quite motivated in proceeding with it.

Miina: So, one thread from there and there and there, like one piece of thread and you've cut it. Then, you take the ends of the threads. Long ones are plus and short ones are minus.
Peppi: Yeah!
Miina: So, you take the long ones', can I show with the battery? (Oona hands the battery). From here to the plus side, so from here to here on top (of the battery), then the ones you've tied here (the minus side), put the thread there and put tape on top and then the LEDs should light up.
Peppi: Oooh! Cool! (excited) I will do the plus side, you (Oona) do the minus!
Miina: So, the long ones are plus …
Oona: Yeah!! (seemingly happy about their progress)

In this example, we witness switching of the student's roles, seemingly important for their agency development. For instance, Miina who first leads and carefully instructs Oona and Peppi to the new challenge, soon allows them to propose their own ideas, the three of them equally contributing to the process and working as a functional team. Later, Peppi and Oona unexpectedly start helping their peer Nora, who has difficulties proceeding with the same Electric Apparel challenge on her own. This is an indication of a significant switch especially in Peppi's role, who had previously wanted the group to rely heavily on the teacher. Miina, Peppi and Oona collectively instruct Nora, confirming the switch in Miina's role from an "expert guide" to a co-creator of new solutions. In this session, Oona, Peppi and Miina successfully complete the first level of the challenge and enthusiastically take a picture of the outcome, uploading it into the FUSE studio website, even though the challenge, which has four levels, has not yet been completed.

In summary, this provides an example of the further emergence and development of transformative agency, embodied in the increased autonomy of the students. The students' interaction begins to move from singular actions, led by individual students toward joint efforts guided by collective motivation and enthusiasm toward the design and making activity. In this challenge, instead of asking the teacher, who had been the core resource for the group during the first session, Oona and Peppi relied on their peer Miina, leading to positive experiences, starting to switch the design and making activity from teacher-instructed to student-driven. However, only Miina continued with the next levels of the Electric Apparel challenge in the following sessions and successfully finished her garment. Oona and Peppi, for unexplained reasons, lost interest in this challenge, wanting to continue working with Riina and Silja in the next FUSE session.

Third example: transfiguring the form and meaning of the activity

During November 2016, Oona, Peppi, Riina and Silja attend two FUSE session to work on a challenge as a group of four. During the two sessions, the group carries out "the Jewelry Designer" challenge in which they can design and make jewelry to wear. The item of jewelry is first drawn and designed by the students on paper and then cut from this with scissors. After that, the jewelry item is drawn by the students on a computer using the sketch up program, to print it on a 3D printer. Lastly, rings, hooks, chains and so forth are attached to the printed jewelry. In this challenge, the teachers (Rose and John) are present in the studio, but the group only approaches Rose for help when they need the instructions of the challenge to be translated from English to Finnish.

This example begins with a totally new, much more positive atmosphere in comparison to the first and the second example. The feelings of frustration and disappointment the girls had previously expressed seemed to have disappeared, perhaps due to the many positive experiences during the session illustrated in our second example. The following excerpt demonstrates how Riina suggests the new challenge to the group, with the aim of the design and making activity being fun for them as a collective (can we do something that is fun). The group becomes excited about this challenge and starts to experience themselves as competent (so we can design), an issue clearly meaningful to the group as a whole in their journey toward "real designers", as the American fellow students presenting the instructions of the challenges in the FUSE website, and as demonstrated in the following excerpt (Oooh! We'll do everything!!).

Riina: Can we do something that is fun? (with an excited and determined voice, Oona also looks excited).

Riina to Oona: Let's make 3D jewelry!! (The students open the instruction video from the FUSE website, immediely start smiling and "bounce" to the music).

Oona: So, we can design!! Uu – I want to do one, can I make a keychain?

Oona and Peppi simultaneously (very enthusiastically): Oooh! We'll do everything!!

Silja who was mainly quiet during the FUSE challenges, but had demonstrated agency via actions through her use of mediating means (digital artifacts and other materials and tools), is now given room by Riina to speak, and starts to propose new patterns of the activity to the group. In the following excerpt, Riina addresses Silja in front of the group as the expert of 3D design (Is it fun to make 3D jewelry?). Silja enters the conversation with novel ideas (e.g., This is the one where you design with the software), translating and re-designing for the group the challenge at hand.

Riina to Silja: Is it fun to make 3D jewelry?

Silja: Mm-m! (nodding, looking positive). I would like to do something that is fun. This is the one where you design with the software.

Peppi: Silja do you want to do this too?

Riina then starts to legitimize her role as leader of the group by strongly encouraging the group to work on this particular challenge (let's make 3D jewelry!), which had provoked their collective interest. Oona and Peppi, who had previously had disagreements, but who had successfully worked as a pair, now show strong common interest and support Riina's leadership. Peppi also starts to follow Riina's example by starting to grant Silja full membership of the group, asking her opinion (do you want to do this too?). The girls then transfigured their design and making activity by reading the instructions of the challenge together, jointly planning how to proceed, and co-designing and co-making the jewelry.

The girls get the kit for the Jewelry Designer challenge and enthusiastically plan to design various kinds of earrings. However, they soon encounter a problem, as they realize that the instructions for this challenge are in English on the FUSE website. They turn to their teacher Rose for help. After gaining a translation of the instructions from Rose, the group starts to design their earrings. Then, they creatively start sketching several designs of their own for the earrings. They collectively reflect on issues, such as what shapes and sizes there could be, what type of earrings each of them fancies and so forth.

This represents an example of the students' motives and joint creative actions going beyond the instructions and demands of the FUSE studio and those of the teacher. As illustrated in the excerpt below, by taking out the materials, which they are not supposed to do at this point, and by totally ignoring the teacher's comments on this (Teacher: you don't take those out until you have …), the group deviates in this session from the instructions given by the teacher and the FUSE website. At this point, all the group members seem happy about how the design and making process is going. The touching of the materials seems like a lot of fun to them, seemingly triggering the students' creative suggestions in the design process.

Peppi: Here are those earrings that hang (takes the Jewelry Designer kit)
Rose (the teacher): You don't take those out until you have …
Riina (ignoring the teacher): Do you have silver or gold? (the students fiddle with the materials despite the teacher's instructions)
Peppi: We have silver and gold. Here are the ones, if your ears are not pierced (very focused and enthusiastic).
Silja: Look how this turned out, look I made this!! (turns the screen to the others and smiles and Peppi comes over to see smiling, their joined work continues).

To our surprise, Peppi, who had previously wanted to rely on the instructions given by the teacher and also resisted the ideas proposed by the other members of the group, now took a stronger leadership position. Silja who had been the quiet one, engages in the conversations, showing enthusiasm and explaining her ideas and discoveries to the other group members. Also, due to Riina's support, she becomes recognized and legitimized by the other group members as an equally-relevant participant in the design and making process. The students found the challenge compelling and were driven by their collective motive to create something novel and uniquely designed by themselves. Yet, the design and making process was not totally without tensions. However, overall, the group conducts this challenge as an interactive group, actively sharing knowledge and guiding one another. Considerably due to Silja's input, the group successfully completed the Jewelry Designer challenge.

To sum up, in this example, the group worked independently, asking the teacher Rose for help only to translate the instructions from English to Finnish. This time, the group did not choose the FUSE challenge randomly, as they had done in the previous sessions, but spent a considerable amount of time to consider and negotiate collectively and carefully which challenge to choose. They started to follow their own ideas and ways of working, changing the direction of the activity further toward the interest-driven form. All of them took part in reading and translating the instructions to

one another. They also all engaged in the creative re-designing of the challenge (creating multiple wonderful designs in a relatively short time period). These two sessions were crucial for legitimizing and sustaining the new solutions and the roles (especially including Peppi and Silja) of the participants in the group. Transfiguring their activity toward a shared object increased its interest-driveness, legitimizing and sustaining the role of the students as a group of "real designers", capable of acting without well-defined instructions.

Discussion

In this socio-cultural and cultural-historical study, we have analyzed how transformative agency manifests itself over time in a school-based, digitally enhanced makerspace of the FUSE studio among a group of elementary school students. We adopted an abductive approach and carried out an in-depth, data-driven empirical analysis through which we explored the emergence and development of transformative agency, paying special attention to tensions emerging in the interactions between the students and their teachers during their design and making activities.

The emergence and development of transformative agency during one school semester were not linear processes. The different manifestations of transformative agency emerged and re-emerged, intertwined and overlapped in the students' design and making activities over time. For instance, tensions were present throughout the FUSE sessions. The group's process of becoming "real designers" was distributed across the students, and evolved over time, "as clusters of volitional actions which break away from well-established constraining frames" (Virkkunen, 2006). Further, the manifestations of transformative agency were in a dialogical relation and intertwined with the material changes in the social practices (see also Haapasaari et al., 2014).

The students' transformative agency had been preliminarily triggered in the first of our examples (mainly by the students deviating from the instructions) and continued in the second example with a switching of roles and the direction of the activity toward an increased interest-driven and learner-centered mode. Given the relatively short time the group spent in the FUSE studio (one semester), we find these developmental changes to be quite impressive. In this process, for example, the quiet student, Silja, utilized the other group members, which helped her to take "a transformative activist stance" (Stetsenko, 2008; Vianna & Stetsenko, 2011), to change the direction of the activity and to legitimize her role in it. More precisely, our investigation of the expressions of transformative agency depicted from the students' discourse and action over time, led to the identification of three intertwined manifestations of transformative agency, emerging and developing as a cyclical, back and forth process; namely, deviating, switching and transfiguring.

In the discourse and actions of deviating, the students coordinated their activity quite randomly, without jointly planning and dividing their labor in the design and making process. This created multiple tensions and deep feelings of frustration and disappointment and the motivation for the task and its shared object seemed missing. Our analysis indicates that even though the FUSE Studio makerspace is based on a pedagogical approach that values students' interests and interest-driven activity, this was not always realized. It is important to note that the students were participating in the FUSE studio for the first time and they were searching for the "script" for the activity. This is especially demanding in a makerspace environment, where the students' learning is not sequentially organized by the teacher or a textbook by a pre-planned script, but one where they must navigate and integrate knowledge from different resources and domains (see also Ludvigsen, 2009). Adding to the complexity, the group chose to carry out different FUSE challenges each time in each of the here presented sessions. The frustration of the students diminished over time as the students progressed with and developed expertise related to the challenges. A strong tension that was present during the whole semester was the one between the promotional aims of the FUSE studio as an interest-driven makerspace and the teacher-given instructions stemming from existing patterns of schooling activity (see also Kumpulainen et al., 2018).

In the switching manifestation of transformative agency, the students' actions seemed more conscious than in deviating, trying to overcome the tensions by proposing creative ideas without the teachers' support. We witnessed this manifestation of transformative agency in the second example, coming close to the notion of relational agency applied in socio-cultural studies (Edwards, 2011, 2017). Yet, in our understanding, the evolution of the students' agency can be seen as something beyond the relations of an individual expert (Miina) and her fellow students. This is due to the fact that the girls started in subsequent sessions to continue each other's suggestions and negotiated possible directions to overcome the multiple difficulties and tensions. The girls had felt low-spirited after the first session, as their expectations of the challenge and the teacher were clearly not met. They tentatively started to seek new, expanded options for their activity. This resulted in disregarding the teacher and turning to a fellow student, who became a co-creator of the challenge, rather than being an instructor-expert.

In the third manifestation of transformative agency, namely, transfiguring, witnessed in our last example, the discourse and actions were increasingly reflexive and the interaction was more inclusive of all of the group members (Silja was also included), and directed learning to a shared object of activity. In this process, Silja utilized her peers Riina and Miina as psychological instruments, in other words as "a second stimulus", which helped her to act agentively and to change the direction of the activity and to legitimize her role in it (Vygotsky, 1978, p. 74; also Engeström, 2007; Rainio, 2009). In this, the students, not randomly, but increasingly purposefully and exceptionally, changed or extended their use of material means, re-organized their activity (Rajala & Sannino, 2015), and almost like activists transformed their expected roles as students (Stetsenko, 2008). Over time, we witnessed preliminary attempts of the students' expansive learning actions (Engeström, 2001) toward the transforming of the object of their activity from the instruction driven actions to an activity based on their own interests. Yet, "the process was predominantly oriented to specific criticisms and stepwise practical improvements rather than to a radical overall change of the object and model of the activity" (Haapasaari et al., 2014, p. 258).

We suggest that transformative agency is especially important for the teachers to recognize and support as it potentially provides opportunities for a complete change of direction in the form and meaning of the activity over time. This is a unique form of collective agency as it allows not only for the development of the shared object-orientation of the activity, but also for the students' creativity (see also Kajamaa et al., 2018; Miettinen, 2013), imagination, independence and collective appearance, ideally allowing all the students to "shine" in the design and making process. This paved the way for overcoming tension-laden situations, reliance on the teacher and provided opportunities for the students' interest-driven learning. To sum up, makerspace allowed for the emergence and development of transformative agency. Managing the new demands and tensions and promoting this type of agency within and outside the makerspace, at the level of the school system, to enhance the implementation of the new curriculum and student-centered pedagogies, is, however, a demanding learning challenge requiring time and a strong commitment and continuous efforts, both from the students and the teachers.

Conclusions

Our findings highlight the potential of technologically-enhanced design and making environments in enhancing the emergence of students' transformative agency in schools. Also, our recent study indicates that such design and making environments can function as transformative devices, promoting students' knowledge creation and building bridges between out-of-school and school knowledge and learning. However, our study also points to the fact that alongside the promotional aspects, makerspaces can sometimes become contradictory contexts, tensions and conflicts emerging in these setting (Kajamaa et al., 2018; see also Kumpulainen et al., 2018; Peppler et al., 2016). The present study shows that even though FUSE is based on interest-driven pedagogy and follows the basic logic of video game design principles, the first time a specific challenge is carried out may be

difficult for the students, as they are familiar with their out-of-school video games. The students may not always be aware of what a personally meaningful design task/challenge is, and where, how, and when they can make choices about their activities.

The present study indicates that new types of pedagogical arrangements involving interest-driven learning can provide students with novel opportunities to resist and to contribute to the transformation of teacher-driven school activities. In the context of this study, the students engaged in composing ideas and plans collaboratively, powerfully extending their expected roles as students, for example, by starting to instruct their peers and the facilitating teachers. Through the analysis of the emergence of transformative agency, our study contributes to better understanding of the complexity of implementation of makerspaces in school environments. Our findings also shed light on the role of digitally enhanced learning environments as promotional spaces for the emergence of transformative agency of student groups, as well as for teachers and students.

Our study adds to the existing research on transformative agency, typically focused on adults in the context of formative interventions carried out in work settings. It makes an original contribution to the existing research on transformative agency by offering an account of how students engage with digitally enhanced design and making practices and develop their agency in this socio-material context. In our study focused on four children, and following and comparing the emergence and development of their agency at the individual level makes sense and is practically possible given the relatively small number of the research subjects. Our findings are in line with previous studies, indicating that individual initiatives and expressions of transformative agency can trigger further expressions, and expanded, collective endeavors and emergence of transformative agency (Haapasaari et al., 2014).

Our study has limitations that should be taken seriously. We focus our analysis on four FUSE sessions in which the girls work as a group, and did not follow them individually in the FUSE sessions they attended in between these. Thus, crucial information may be lost from the viewpoint of the students' agency and identity development. We also acknowledge that our analysis is restricted to a FUSE studio makerspace located within the formal institutional context of school. The FUSE studio sessions are restricted with certain structures, rules and time frames and due to the aims and traditions of schooling, the teachers often try to maintain control over the students in these environments. Even though the FUSE studio represents an infrastructure based on students' interests, its challenges and instructions are pre-defined and well-framed. As we learned often, these are experienced as being restrictive by the students (and in many cases also by the teachers). This makes the facilitation of learning processes enhancing transformative agency and interest-driveness a challenge both for students and their teachers. Haapasaari et al. (2014, p. 259) state "the longevity and sustainability of these changes in the work activity of the group can only be assessed by means of data collected over a lengthy follow-up period". We agree with these statements and call for new longitudinal studies on students' transformative agency in novel digital makerspaces.

Data availability statement

We do not have ethics approval to make the raw data from this study available for sharing. The research on which this study is based follows the ethical standards set forth by the Finnish National Board on Research Integrity. A formal record provided by the Data Protection Ombudsman in Finland was submitted to the City of Helsinki regarding personal data processing in the research project. Written permission to conduct the research was acquired from the City of Helsinki and its two schools, including the principal and teachers in which the research took place. The students' guardians were informed about the research and its data collection methods and were asked to give their written consent for their children's participation in the research. Participation in the research was voluntary and could be ended at any time. The research respects the teachers' and children's anonymity and privacy, and all names mentioned in the research are pseudonyms. The research data cannot be shared outside the research group with any third parties.

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